BOX 1
Relationship Between Angle of Attack and Lift

The angle of attack (AOA) is a measurement of how steeply a plane is flying. Specifically, it is the angle between the chord of a plane's wing and relative air flow. At low angles, drag is low and therefore less energy is required to propel the plane. But lift (the upward force that opposes the pull of gravity) is also lower, which decreases the load that a plane can carry. At high angles of attack, lift is higher and the plane can carry more fuel or cargo. Drag is also higher, however, and fuel efficiency declines.

This general relationship between AOA and lift is true only over a limited range. At some point, a higher AOA no longer results in greater lift because the high angle of the wing to the air flow creates turbulence, disrupting the required smooth flow of air over the wing and causing an aerodynamic stall. On most planes, this point determines the maximum AOA at which the plane can fly. An advantage of this condition is that the turbulence indicates to the pilot that the plane is approaching its maximum AOA.

On the B-1B and some other planes, however, an aerodynamic stall is not the factor limiting the angle of attack. Indeed, before the B-1B can use the greater lifting capability available at higher angles of attack, the plane is potentially unstable. As the AOA increases, the plane shifts from positive static stability (the center of gravity is in front of the center of lift) where the flight control system (FCS) can easily control the plane's pitch, to neutral or negative static stability (the center of gravity is even with or behind the center of lift) where it is difficult for the FCS to control pitch.

In this situation, where the plane's maximum angle of attack is determined by potential instability rather than by aerodynamic stall, there is no buffeting to warn the pilot that the plane is close to exceeding the maximum AOA. Thus, the B-1B employs mechanical signals--a light and a siren--to warn the pilot.

Determining the maximum AOA in this situation requires subjective evaluation of the flight control system's ability to maintain control of the plane. The Air Force has determined that, in order to allow an adequate margin of safety, the B-1B's basic FCS can operate the plane at 80 percent of the "limit" AOA (defined as the AOA that corresponds to neutral static stability); the FCS triggers the warning light and siren at that point. With the Stall Inhibitor System (SIS), however, the Air Force anticipates that the bomber could operate at 95 percent of the "limit" AOA and thus the light and siren will be triggered at that level. With the Stability Enhancement Function (SEF), the plane may be able to fly at even higher angles of attack. By increasing the operational limits on the angle of attack, SIS and SEF will enable the B-1B to use some of its previously unexploited lift capability.

replace mechanical links, employs a computer called the Stability Control Augmentation System (SCAS). The SCAS interprets the pilot's instructions (based on pressure on the stick) and augments the mechanical system to achieve the desired angle of attack.

The Stall Inhibitor System is essentially a computer that modifies the fly-by-wire side of the basic FCS. It compares the actual AOA with the maximum, or "limit," AOA for current flight conditions. As the actual AOA approaches the limit AOA, SIS cancels part of the signal forwarded to SCAS, thereby forcing the pilot to pull much harder on the stick to fly the bomber at higher angles of attack where it might go out of control.

With this system, the Air Force anticipates that the bomber will have greater maneuverability, flying at 95 percent--compared with 80 percent with the basic FCS--of the limit angle of attack. The Air Force estimates that this improvement would enable the B-1B to carry about 30,000 more pounds of fuel or weapons during high-speed, terrain-following flight. Using this increase for fuel would extend the terrain-following range of the B-1B by roughly 500 miles.

In addition to increasing the B-1B's payload capacity at low altitudes, the ability to fly at higher angles of attack increases the bomber's maneuvering capability when taking off and landing. Flying at a higher angle of attack also enables a bomber to refuel at a higher altitude, improving fuel efficiency and making it less likely that the bomber and tanker will have to refuel while flying through clouds, precipitation, and turbulent air.

The testing and installation of SIS is proceeding in two parts. The first 18 B-1B aircraft were built without any SIS hardware. The testing of SIS hardware--termed SIS1--for those aircraft was completed in March 1988. According to the Air Force B-1B Program Office, the system is working well and no major problems have been encountered. Installation of SIS1 was completed in June 1988. On the other 82 aircraft, the installation of SIS--termed SIS2--began in March 1988 and is scheduled for completion in June 1990. Although SIS2 produces the same performance parameters as SIS1, SIS2 uses the same hardware as the Stability Enhancement Function, discussed below.

The Stability Enhancement Function. The Stability Enhancement Function (SEF) operates much like SIS but it uses additional sensors and refined software to evaluate more clearly the conditions under which the bomber can be safely flown. SEF is designed to permit the pilot to fly the B-1B at high angles of attack--potentially in excess of the limit AOA--when it is safe to do so. The Air Force estimates that the B-1B with SEF will be able to carry up to 110,000 more pounds of fuel or munitions during high-speed, terrain-following flight than if it were equipped only with the basic flight control system. Whereas the Air Force's estimate for SIS is based on substantial testing, however, the estimate for SEF is based on preliminary engineering evaluations and could change substantially.

If the anticipated increase in payload with SEF is used to carry fuel, the terrain-following range of the B-1B could increase, compared with current capability, by about 1,700 miles. Figure 3 compares the range of the B-1B equipped with the basic flight control system, with SIS, and with SEF.

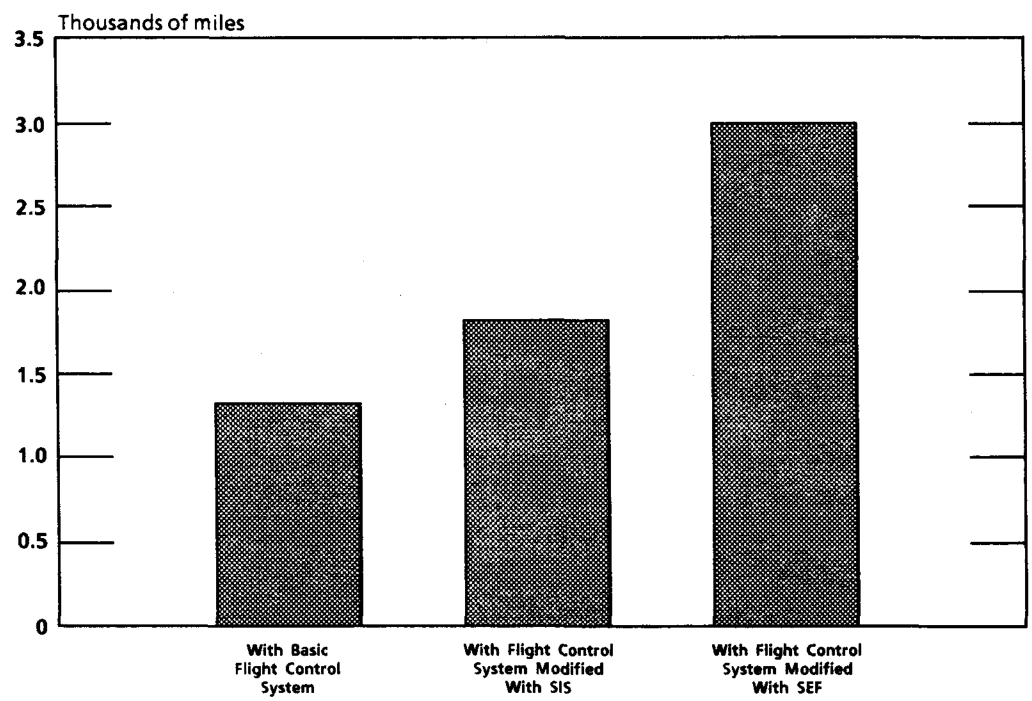
The testing of SEF began in March 1988 and is scheduled for completion in February 1989. The retrofit of SEF is scheduled to occur in two parts. The B-1Bs with SIS1 are to be retrofitted between November 1988 and January 1992. The other B-1Bs are receiving SEF simultaneously with SIS2, between March 1988 and June 1990.

Offensive Avionics: A High Rate of Unnecessary Flyups

Offensive avionics comprise electronic hardware and computer software designed to guide a plane and its weapons to the target. Major elements of the offensive avionics suite on the B-1B bomber are an inertial navigation system (gives current location), a radar altimeter (measures height above the ground), a Doppler navigation radar (measures velocity), and the offensive radar system. The offensive radar system can operate in many different mapping and navigation modes, but the two most important are high-resolution ground mapping and terrain following. The former mode provides maps that help identify targets and feed targeting data to weapons systems. The terrain-following mode makes a profile of the terrain directly ahead of the bomber so that it can fly close to the ground without crashing.

The terrain-following mode is used in the automatic terrain-following (ATF) system, which is essential for low-altitude penetration (see Box 2). The ATF system on the B-1B, however, has suffered from a high rate of unnecessary flyups: the ATF instructs the aircraft to pitch up fast even though there is no obstacle. These unnecessary flyups have been caused by the ATF's detection of nonexistent hills and by "invalid" signals in which the system checks itself and concludes that it is not working satisfactorily. Flyups are a major problem because they expose the aircraft to detection by ground-based radars, waste fuel, and reduce the crew's confidence in the ATF system.

Figure 3.
Approximate Range of B-1B Bomber During Terrain-following Flight at Low Altitudes



SOURCE: Congressional Budget Office analysis of data provided by the Air Force. See Appendix A for discussion of the methodology employed.

NOTE: SIS = Stall Inhibitor System; SEF = Stability Enhancement Function.

BOX 2
Automatic Terrain-following System

The automatic terrain-following (ATF) system is essential for flying close (200 to 400 feet) to the ground. Such flying is difficult when relying on vision alone under the best of conditions (calm, clear weather) and is nearly impossible under more adverse conditions. In addition, a strategic nuclear mission might be conducted at night, and the cockpit windows might be covered by thermal curtains to protect the crew from the flash from a nuclear explosion, making it impossible to fly by vision alone. Finally, flying by vision alone would require such concentration that the pilot would have little opportunity to monitor other important activities. During high-speed, low-altitude penetration, a pilot would be flying only 200 to 400 feet off the ground while traveling more than 900 feet per second. Just one second of inattention or confusion could result in a crash.

The ATF system operates by scanning the terrain ahead with a radar beam and building a profile of that terrain in its memory. If the terrain is flat, these scans can occur many seconds apart, giving the offensive radar system time to devote to other functions such as making high-resolution ground maps. If the terrain is hilly or mountainous, the ATF must scan more often.

The ATF has several safeguards to ensure that the bomber does not crash as a result of a failure in the ATF system. First, if the altimeter indicates that the bomber has moved out of a predetermined tolerance band around the desired elevation, the ATF will trigger an automatic flyup, in which the bomber accelerates rapidly upward to avoid a potential crash.

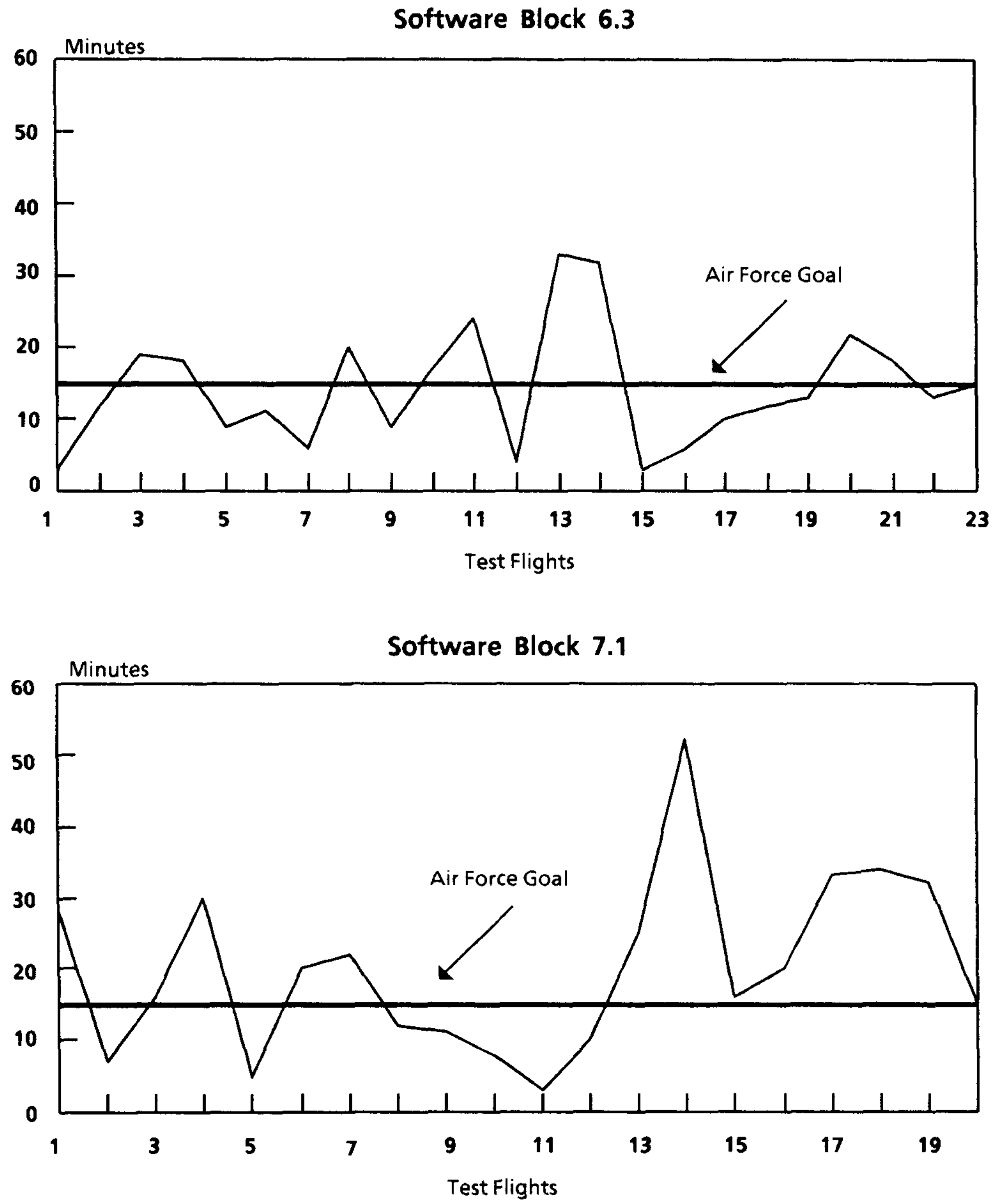
Second, the ATF checks its own performance about 16 times per second. At the end of each check or "frame," the ATF computer sends a "valid" signal to the flight control system if it is working correctly and an "invalid" signal if it is not. More than 500 conditions would cause an invalid signal to be registered. If such a signal is registered several times in a row, the ATF system triggers an automatic flyup.

Another disconcerting but less significant problem occurs when the ATF system directs the plane to pitch down as the bomber approaches a large obstacle. This problem, according to the B-1B Program Office, occurs when the bomber is turning. The ATF system on one scan detects a small hill and instructs the plane to pitch down as the plane passes over it. As the plane begins to pitch down, however, it confronts a larger obstacle that was not in the direct line-of-sight on the previous scan and was therefore undetected. The Air Force believes that the solution is to change the software to limit the rate and magnitude of pitch-downs, smoothing the transition from one scan to the next. The pitch-down problem is being addressed in software scheduled to be flight-tested and delivered to the Strategic Air Command by September 1988.

The Air Force maintains that the excessive flyups, like the disconcerting pitch-downs, can be solved largely by fine-tuning software. Three types of software are involved: the automatic flight software that controls basic aircraft navigation; software that computes the desired flight path; and offensive radar software that controls the radar that maps the terrain ahead of the aircraft. The Air Force is developing, testing, and periodically deploying improved versions of these software packages with the goal of raising the mean time between unnecessary flyups to 15 minutes over all types of terrain.

Between June 1987 and February 1988, the Air Force worked on improving the offensive radar software, testing versions known as block 6.3 and block 7.1. The Air Force data on these tests are not sufficient to demonstrate that substantial progress has been made in resolving the problem of unnecessary flyups. The data show that the mean time between unnecessary flyups on test flights has varied widely, between 3 minutes and more than 50 minutes (see Figure 4). In addition, the data do not paint a clear picture of performance of the ATF system, because they neither provide the length of test flights nor distinguish between test flights conducted under widely varying conditions. Conditions that could influence the performance of the ATF system include weather, the type of terrain covered, the altitude at which the test was conducted, and whether the system was set for a "hard ride" (the bomber follows the terrain more precisely, necessitating more rapid changes in elevation) or a "soft" ride. Finally, the per-

Figure 4.
Mean Time Between Flyups During Test Flights Using Software Blocks 6.3 and 7.1, June 1987 to February 1988



SOURCE: Compiled by Congressional Budget Office using Air Force data.

formance of the ATF system on carefully regulated test flights might not be representative of its performance on deployed aircraft.

The Air Force, while acknowledging that recent data do not provide any identifiable trends, notes that many necessary corrections have been deferred to version 4.5 of the automatic flight software and version 8.1 of the offensive radar software and that, when these versions are fielded, substantial improvement should be made.

In summary, it appears that additional work must be done before the ATF system on deployed aircraft will meet the Air Force performance goal. If the B-1B Program Office is correct in believing that there is no fundamental problem in the ATF hardware, however, work on the software should continue to yield improved performance, eventually meeting the Air Force objectives.

Shortcomings in Logistical Support

A weapons system must be maintained and supported to operate effectively. Logistical requirements include facilities for servicing the aircraft, trained maintenance personnel and flight crews, and adequate supplies of spare parts. To date, the major logistical problems have been insufficient training of crews and lack of spare parts.

Insufficient Training at Low Altitudes. While the Air Force has almost as many crews as desired for the B-1B bombers, those crews have not received an adequate amount of training in flying the B-1B at low altitudes.

Regarding the number of crews, the Air Force has come close to meeting its desired crew ratio (qualified B-1B crews to primary authorized aircraft) of 1.0 during B-1B deployment. As of February 24, 1988, for example, the Air Force had 80 crews for 83 aircraft, with five additional crews nearing graduation. The Air Force also expects to meet its future goals for crew ratios of 1.1 between July 1988 and April 1991 and 1.3 by December 1993.

Many B-1B crews, however, have not had the desired level of training in low-altitude flight, which is essential for accomplishing the B-1B's penetrating mission. This shortcoming is partially the result of fewer aircraft being available than was planned--either because they have been in the shop being modified or have been grounded by shortages in spare parts. In addition, low-altitude training was interrupted following the crash of a B-1B during a low-altitude training flight in September 1987. The Air Force therefore established a training schedule to recertify flight crews that were certified before the September crash as well as to certify new crews. As of July 1988, 95 percent of the crews that were certified before the crash had been recertified, and 5 percent of the new crews had been certified. The Air Force anticipates that the remaining crews will be certified by November 1988.

Insufficient Spare Parts. Virtually every sophisticated weapons system suffers from an inadequate supply of spare parts in the first few years of deployment. Supplying parts for aircraft in production takes priority over supplying parts for the inventory of spares. In addition, until the aircraft has been flown, the rate at which various parts will fail can only be roughly predicted. Changes in design among production aircraft complicate the fielding of spares, and budgetary pressures during production encourage the postponement of funding for the procurement of spares.

The B-1B bomber has been no exception to the problem of inadequate spares. Shortages have adversely affected the availability of aircraft both for training and, if necessary, for strategic missions.

The Air Force uses several measures to track shortages of parts including "canns" and "MICAPs." The picture painted by these measures is mixed. The number of "canns"--parts taken from some aircraft to keep other aircraft operating ("canns" is short for "cannibalizations")--per B-1B sortie have oscillated between 0.9 per sortie and 2.2 per sortie between November 1987 and April 1988 (see Figure 5). As the supply of parts improves, a consistent decrease in the number of canns should be evident. The number of "MICAPs"--parts on back order that are considered necessary for performing a mission ("MICAP" stands for "mission incapable part")--has decreased from a total of 935 in September 1987 to 478 in February 1988.

Other measures provide an indication of the impact of spares shortages and modification programs on operations. One measure is

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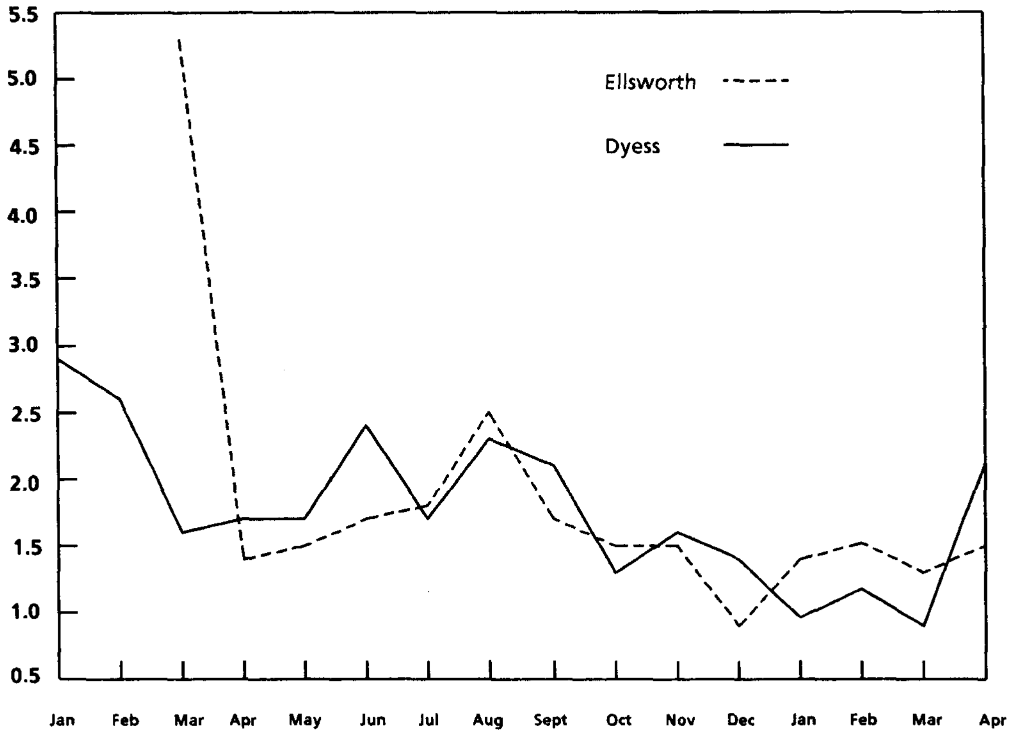
Figure 5.
B-1B Logistical Support as Measured by "Canns" per Sortie at Two Air Force Bases, January 1987 to April 1988



SOURCE: Compiled by Congressional Budget Office using Air Force data.

NOTE: "Canns," short for "cannibalizations," are parts taken from some aircraft to keep other aircraft operating.

the percentage of planned training sorties that the Air Force was able to fly. This measure has increased to 90 percent for the period from October 1987 to January 1988. A second measure is the percentage of deployed aircraft that are fully or partially mission capable. At Dyess Air Force Base, this measure has been as follows:[4]

4. B-1B Operational Test and Evaluation Quarterly Status Reports by the Air Force Operational Test and Evaluation Center (September 1987, January 1988, April 1988, and July 1988).

June-August, 1987	36.2 percent
September-December, 1987	28.2 percent
January-March, 1988	45.9 percent
April-June, 1988	34.1 percent

The eventual goal for this measure is 60 percent to 70 percent.

The Air Force has maintained that the shortages of spare parts will improve substantially in the months ahead, noting that the number of delivered parts is increasing and that the industrial capacity that sustained the B-1B production line can now be diverted to fill the spares pipeline. On the other hand, the greater number of sorties now being flown by the fully deployed B-1B fleet is generating a higher demand for parts.

Too many assumptions are involved for the Congressional Budget Office to forecast the outcome of this struggle between supply and demand on the availability of parts during the next year. But the shortage will probably be alleviated over the next several years if the budget for spare parts is adequately funded.

MINOR PROBLEMS

Many other issues have been raised about the B-1B, including interference between the offensive and defensive avionics, the number of fuel leaks, the performance of the on-board Central Integrated Test System, the weight of the aircraft, the capability of the anti-icing system, inadequate preparation for conventional missions, and problems with carrying and launching various weapons. In addition, the crash of a B-1B bomber after hitting a large bird has raised the issue of whether the B-1B needed modifications to decrease its vulnerability to birds. These issues are addressed briefly below.

Integration of Offensive and Defensive Avionics

One challenge in building a sophisticated bomber is integrating the offensive avionics system, which guides the bomber and weapons to the target, with the defensive avionics system, which watches for hostile defenses and helps outwit them. The problem is that radar transmissions from the offensive avionics can "leak" into receiving antennas serving the defensive avionics or vice versa.

The B-1B Program Office reports that tests of the B-1B show that the leakage from the offensive and defensive transmitters into the defensive and offensive receivers has not been at levels high enough to cause identifiable problems. To ensure that no problems occur, however, the B-1B has a Radio Frequency Signal Management System to coordinate the offensive and defensive systems. That system has experienced several difficulties, but it appears that they have either been solved or are being addressed (see Box 3). The Air Force, having growing confidence in the compatibility of offensive and defensive systems, has begun to lift restrictions that had been placed on operating them simultaneously during training flights.

Nevertheless, as long as the Air Force continues to modify the B-1B's offensive and defensive avionics, it must keep testing for potential problems of compatibility to make sure that such problems do not go undetected and either cause a crash or disrupt operation of the bomber's defensive avionics.

Fuel Leaks

Fuel in the B-1B is stored in cells within the airframe of the aircraft, including the wings. To save weight, no special lining or fuel bladder is used. The absence of a lining creates a challenge: nearly 300,000 fasteners penetrate the surfaces of the fuel cells, and each fastener must be effectively sealed to avoid a leak. This sealing procedure was not rigorous enough in the first group of B-1Bs, leading to extensive "weeping and seeping" of fuel from various cells. In some cases, such leaks were simply an annoyance and could temporarily be dealt with by not using a particular cell. In others, the leaks grounded the B-1B.

To solve this problem, the Air Force focused much more attention on the sealing process, establishing repair teams and a better system for training technicians, tracking leaks, and inspecting the work performed. These efforts have yielded improvements. Although the

BOX 3

Radio Frequency Signal Management System

The B-1B has a Radio Frequency Signal Management System (RFSMS) embedded in the offensive and defensive avionics systems to prevent them from jamming or confusing each other.

To prevent the defensive system from attempting to classify radar emissions from the offensive system as a defensive threat, the offensive system notifies the defensive system of the frequencies it is using so that the defensive system can ignore them. To prevent the defensive transmissions designed to jam enemy radars from interfering with offensive avionics, the defensive system sends an "avoid" command to the offensive system, instructing it not to employ the band the defensive system is using. When no longer transmitting on that band, the defensive system should send a "delete" command instructing the offensive system to resume employing that band when it is needed.

The RFSMS has experienced at least two problems. First, the offensive system was not keeping track of the "avoid" frequencies correctly, causing it to transmit at times on the banned frequencies. Second, the defensive system would send the "avoid" commands but would fail to send the subsequent "delete" commands, progressively decreasing the number of frequencies the offensive system could use.

According to the B-1B Program Office, the first problem, which required modifications to the Boeing software for the offensive multimode radar, has been solved; improved software has been installed in the deployed B-1Bs. A solution has been identified for the second problem and was to be installed with Mod 1 of the defensive avionics system. This plan might be altered, however, by the current Air Force reevaluation of plans for improving the B-1B's defensive avionics. According to the B-1B Program Office, although the second problem still exists, the operational implications are modest; before the offensive system fails as a result of receiving too many "avoid" signals, the offensive software will opt to ignore them.

average time between leaks each month varies widely as a result of changes of weather, the amount of flying (temperature-induced expansions and contractions as well as flexing during flight cause leaks), and possibly changes in the way leaks are evaluated and reported, the leaks no longer seriously diminish the readiness of the B-1B fleet.

At Dyess Air Force Base, for example, the average flight time between fuel leaks has risen from about five hours to between 15 hours and 70 hours (see Figure 6). Since the first group of B-1B aircraft were deployed at Dyess, this primarily reflects efforts to fix deployed aircraft. At Ellsworth Air Force Base the average flight time between fuel leaks has risen from about five hours to an average of more than 40 hours (see Figure 6). The performance of aircraft at Ellsworth primarily reflects improved workmanship done at the factory before the B-1Bs were deployed. Therefore, although the Air Force is still short of its goal of an average of 130 hours of flight between each fuel leak, significant progress has been made.

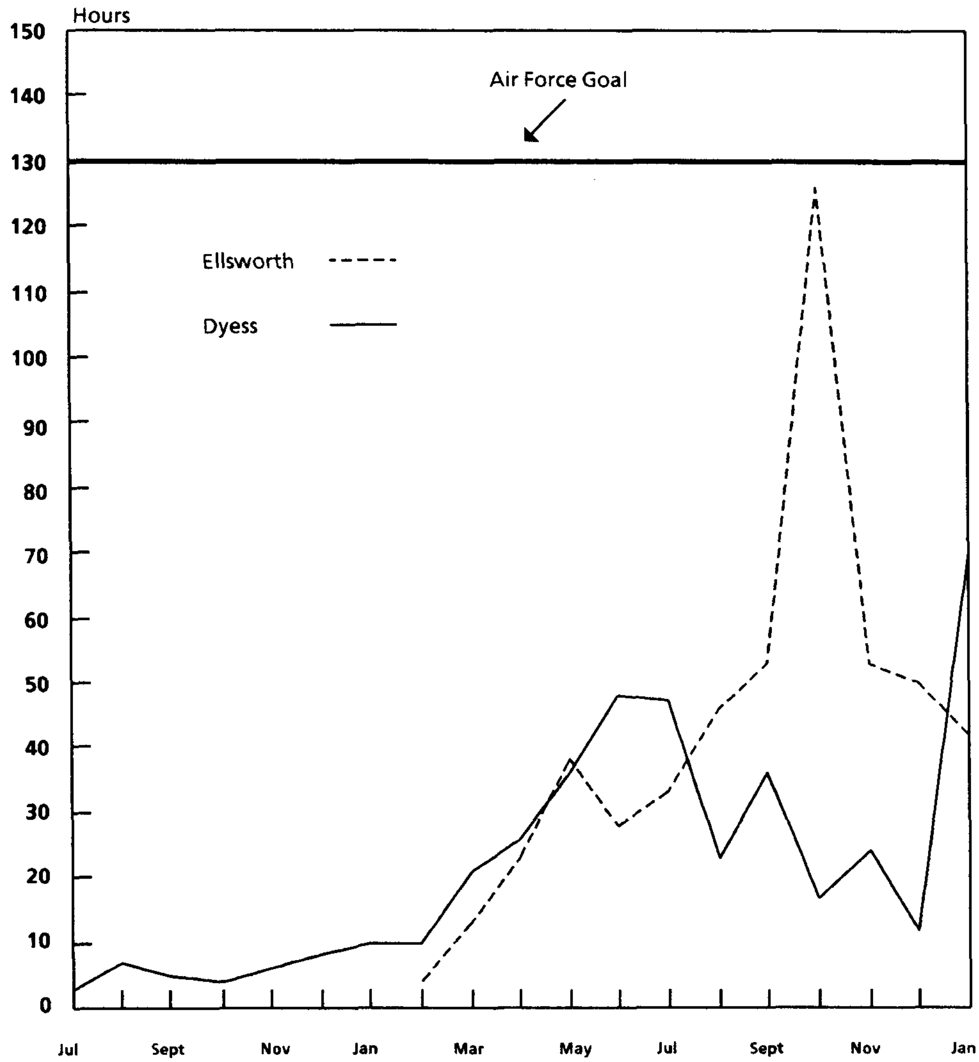
Problems with the Central Integrated Test System

To help technicians on the ground maintain the B-1B, the bomber has a Central Integrated Test System (CITS). This system monitors 22,000 parameters in the airframe, the offensive avionics, and the defensive avionics and then issues any of more than 10,000 different maintenance codes to identify problems. During testing of the B-1B, however, CITS issued as many as 350 false alarms (incorrect identification of a problem) per sortie. This high rate of false alarms greatly diminished the usefulness of the system as an aid to maintenance technicians.

The system's high rate of false alarms was caused partly by faulty hardware but mostly by faulty software. The Air Force addressed the hardware problems, such as sensors that failed to operate correctly, by replacing the faulty equipment. The Air Force also has steadily improved the software.

As a result, the portions of CITS that monitor the airframe and the offensive avionics are now performing well. In tests, false alarms regarding the airframe have dropped from an average of 120 per flight to an average of 20. Flight tests also indicate that the most recent

Figure 6.
Average Flight Time Between Fuel Leaks at Two Air Force Bases, July 1986 to January 1988



SOURCE: U.S. Air Force.

software version will have an average of about nine false alarms per flight.[5] These figures are for the software employed on aircraft num-

5. The data available from the Air Force are based on false alarms per flight, not false alarms per flight hour. The Congressional Budget Office has not been able to determine whether the length and complexity of the flights generating the data have remained constant over time. Such changes could make the data appear more or less favorable than is merited.

bered 2 through 18. Results are even better for the software employed on subsequent aircraft. The false alarm rate has dropped from about 95 per flight to about three per flight. In addition, testing of the most recent software edition indicates the false alarm rate might fall to as low as one per flight.

The rate of false alarms regarding the offensive avionics has dropped from an average of 17 per flight to about nine per flight. Flight test data on the most recent software indicate the rate might drop to about two per flight. That version was installed on the B-1Bs in February 1988.

The portion of CITS that monitors the defensive avionics, however, is not yet performing well. Part of the problem has been that an early software error prevented all but about six of more than 250 maintenance codes for the defensive avionics from being generated. In addition, work has been held back by the immature state of the defensive avionics system. Indeed, further progress on CITS for that system will now depend on how the Air Force chooses to modify the defensive avionics following its current review.

Reports that the B-1B is Overweight

Many reports in the press have claimed that the B-1B is 40 tons overweight and, as a result, cannot fly high enough when cruising and refueling.[6] But these reports are misinformed.

The B-1B is not overweight. The B-1A had a designed empty weight of 174,300 pounds, while the B-1B has an empty weight of approximately 182,360 pounds. Thus, the B-1B is about 8,000 pounds (4.6 percent) heavier than the B-1A. But this extra weight results in part from structural changes that enable the B-1B to carry a larger payload internally and cruise missiles externally. Of the 8,000-pound increase in weight, about 1,300 pounds is attributable to changes in structure, 800 pounds to changes in propulsion, 2,500 pounds to changes in offensive and defensive avionics, and the rest to changes in other systems.

6. See, for example, "The B-1 Bomber: A Flying Lemon," *U.S. News and World Report* (November 24, 1986), p. 29; and "Debut of the Wrong Bomber," *New York Times*, December 12, 1986.

As a result of these structural changes, the B-1B could carry about 30,000 more pounds of fuel and munitions than the B-1A on the high-altitude portions of a penetrating mission. In addition, whereas the B-1A was not designed to carry munitions externally, the B-1B could carry up to about 50,000 pounds of munitions externally, enabling it to carry air-launched cruise missiles on a standoff mission.

Two other questions have been raised about the B-1B's payload capacity: Does flying at greater weights decrease the B-1B's optimum cruise altitude and, if so, is the lower cruise altitude a problem? Does flying at greater weights affect aerial refueling?

Optimum Cruise Altitude. When flying from the United States to a distant target, it is advantageous to fly at a speed and altitude that maximize fuel efficiency, thereby increasing the bomber's range and decreasing the demand for aerial refueling. If the B-1B exploits its structural weight-carrying capacity and flies with more fuel or munitions, the optimum cruise altitude decreases (see Figure 7).

This decrease in optimum cruise altitude, however, is basically irrelevant to the bomber's ability to perform its mission. Flying at 20,000 feet while en route to the Soviet Union is no more dangerous than flying at 35,000 feet. Once the bomber is within range of Soviet air defenses, of course, it would switch to a low-altitude approach.

Aerial Refueling. To reach targets in the Soviet Union, the B-1B must be refueled en route from a tanker aircraft. It is preferable to refuel at altitudes above approximately 20,000 feet since, below that level, the bomber and its tanker are more likely to have to fly through clouds, precipitation, and turbulent air, which can complicate the process of transferring fuel. In addition, fuel efficiency generally improves at higher altitudes.

The B-1B, when equipped with the basic flight control system, cannot always refuel above 20,000 feet. The refueling altitude falls below 20,000 feet when the B-1B's weight exceeds 350,000 pounds (see Figure 8). At 430,000 pounds, the refueling altitude drops to between 10,000 and 13,000 feet.

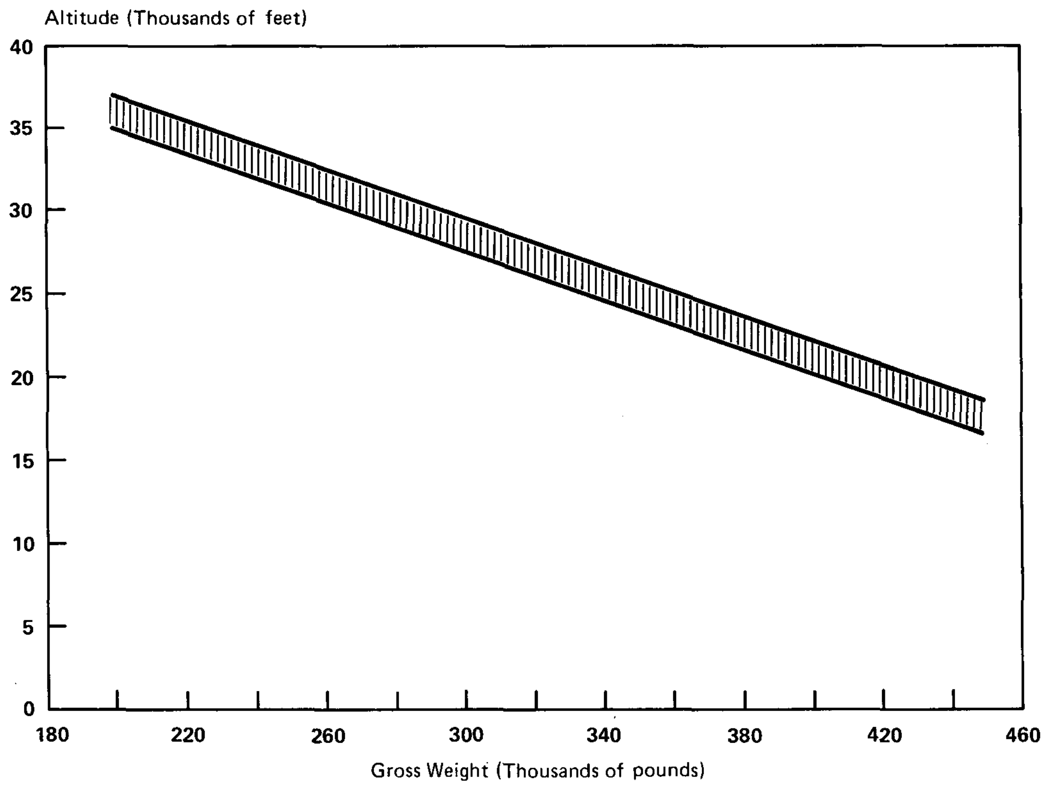
This situation is being improved, however, by the deployment of the Stall Inhibitor System on the B-1B. For example, at a velocity of

368 miles per hour and a gross weight of 400,000 pounds, the B-1B equipped with SIS is able to refuel at nearly 20,000 feet rather than at about 14,000 feet (see Figure 8).

Ice Damage to Engines

The B-1B has an anti-icing system that attempts to prevent ice from building up in flight at places where it might break loose and enter the engines. Ice has been building up in some unanticipated places on the B-1B, however, then breaking loose and damaging fan blades in the

Figure 7.
B-1B's Optimum Cruise Altitudes as a Function of Gross Weight

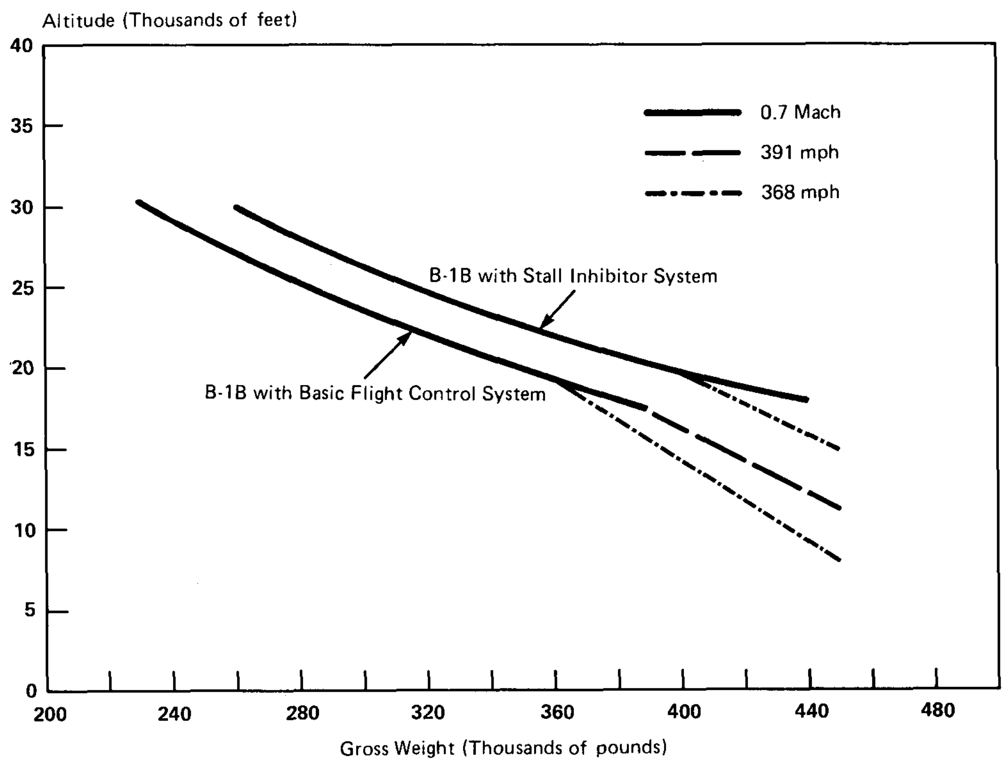


Source: Congressional Budget Office analysis of data from the U.S. Air Force.

first stage of the engines. This ice buildup creates a maintenance problem since damaged blades must be replaced. Although the ice has not yet damaged an engine enough to endanger an aircraft or prevent it from completing a wartime mission, the ice presents at least a small risk of such results.

The Air Force has conducted wind-tunnel tests to study this problem. Based on those tests, which were completed in June 1988, the service is designing an improved system for preventing ice buildup. A prototype is scheduled to be installed on a B-1B for tests in November

Figure 8.
B-1B's Refueling Altitudes as a Function of Gross Weight



Assumptions: Bomber is flying with 25-degree wing sweep and maintaining the ability to pull up at 1.3 g's without exceeding a safe angle of attack.

SOURCE: U.S. Air Force.

1988. Pending deployment of this improved system, the B-1Bs on training missions are permitted to fly only for a limited number of minutes under conditions that could cause ice to form on the plane.

Preparation for Conventional Missions

During testimony in support of development and procurement of the B-1B, the Air Force indicated that it would prepare the B-1B to conduct conventional missions as well as strategic nuclear missions.[7] The Air Force has fulfilled this commitment by certifying the B-1B's capability to carry conventional bombs.

Some analysts argue, however, that this certification is only symbolic. For the B-1B to have a significant conventional role, the Air Force needs to procure standoff munitions and War Readiness Spares Kits--neither of which are funded in the current Air Force budget.

Standoff munitions are needed because the B-1B is too valuable for the risky mission of flying over a target and dropping conventional bombs. Because of the risks inherent in dropping bombs, for example, the Air Force is planning to field precision-guided standoff munitions for its B-52G bombers assigned to conventional missions.[8] The Air Force states that it does not have a plan for providing such munitions for its B-1B bombers.

If the Air Force intends to make the B-1B available for multiple conventional sorties in an extended conventional conflict, it would probably need kits of spares to support the surge in demand for parts.[9] The Air Force has no funds budgeted to procure such kits for the B-1B.

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7. See testimony by Lt. General Kelly H. Burke, *Strategic Force Modernization Programs*, Hearings before the Subcommittee on Strategic and Theater Nuclear Forces of the Senate Committee on Armed Services, 97:1 (1981), p. 330.

8. See testimony by Major General Michael Loh, *Department of Defense Authorization for Appropriations for Fiscal Years 1988 and 1989: Part 4, Strategic Forces and Nuclear Deterrence*, Hearings before the Senate Committee on Armed Services, 100:1 (1988), pp. 2079-2081.

9. In 1981, the Air Force compared the potential conventional use of the B-1B to the use of B-52 bombers in Vietnam and B-29 bombers in Korea, where aircraft flew multiple conventional sorties. See testimony by Lt. General Kelly H. Burke, *Strategic Force Modernization Programs*, Hearings before the Subcommittee on Strategic and Theater Nuclear Forces of the Senate Committee on Armed Services, 97:1 (1981), p. 330.

Thus, the B-1B is currently ill-prepared for many conventional conflicts where the targets are well defended or multiple sorties are required. As currently configured, the bomber could be used for single sorties against poorly defended targets, but the Air Force has a number of other aircraft well suited to that task.

Problems with Carrying Cruise Missiles Externally

The Air Force conducted five flight tests of the B-1B between December 1987 and July 1988 to analyze its ability to carry advanced cruise missiles externally.[10] These tests revealed that when the B-1B bomber is flying at low altitudes and high speeds, some of these missiles were subjected to acoustic levels of up to 165 decibels. The ACM was designed to withstand only 162 decibels, however, raising concerns that the B-1B might not be able to carry ACMs externally.

These concerns are probably not justified. At the higher altitudes and slower speeds characteristic of flights with cruise missiles, the acoustic levels were lower than those noted above (the acoustic level is highly dependent on air density and aircraft velocity). Thus, the acoustic levels generated outside the B-1B may not pose any problem for ordinary standoff or shoot-and-penetrate missions conducted with cruise missiles.

In addition, the external acoustic levels vary considerably with the cruise missile stations. The missiles are carried in three rows of four missiles each under the fuselage. The acoustic level is higher in the rear row than in the middle row and is higher at the outside of the rear row than at the inside. Thus, if there is an acoustic problem on normal missions with external cruise missiles, it might be solved by removing the two outside aft cruise missiles and carrying only 10 cruise missiles externally rather than 12.

10. The Air Force may have tested the ACM rather than the ALCM-B for two reasons. First, since the Air Force does not plan to carry cruise missiles on the B-1B until well into the 1990s, and possibly the end of the 1990s, the B-1B would probably be deployed with the ACM rather than the ALCM-B. Also, since the ACM is only beginning to enter production, the Air Force might still be able to make engineering changes in the missile that would facilitate carrying it externally.

Problems with Launching the SRAM-A

Launching SRAM-A missiles from the rear bay has been complicated by turbulence under the aircraft that causes the SRAMs to pitch down to such a degree that they cannot recover to perform their mission. In February 1988, the Air Force tested potential remedies. A workable solution has been found that consists of repositioning the doors of the middle bay (leaving them further open or closed) and the spoiler (a panel that drops down in front of each bay) to change the dynamics of the turbulence.

Problems with Launching Conventional Bombs

As noted above, the Air Force has given the B-1B the capability to carry some conventional bombs, one of which is the Mk-82. A problem has emerged, however, in carrying that munition--the bomb rack cannot be loaded safely without cumbersome procedures. The Air Force has therefore redesigned the bomb rack. Flight tests of the new rack began in April 1988, and certification is planned for autumn 1988. There has also been a problem in dropping the Mk-82 from the rear bay. The Air Force has found that opening the doors of the middle bay has solved the problem. Tests of dropping the Mk-82 from all three bays were conducted in March 1988 and confirmed that the solution is adequate.

Bird Strikes

On September 28, 1987, a B-1B bomber engaged in low-altitude training struck a large bird and crashed, killing three crew members.[11] The bird apparently hit the support between one set of engines and a wing, ripping through the bomber's skin and destroying various fuel and hydraulic lines.

11. Three crew members, who were in ejection seats that functioned correctly, survived the accident. One crew member whose seat did not function correctly, and two who were not in ejection seats, died in the crash.

The Air Force immediately suspended low-altitude training and, after investigating the accident, decided to strengthen three vulnerable points on the B-1B bombers: the support structure connecting the engine nacelle to the wing (a steel and kevlar shield is placed under the skin); the base of the tail of the aircraft (a steel shield is placed under the skin to protect the actuator for the horizontal stabilizer); and the point where the movable wings join the fuselage (a kevlar curtain is attached to the fuselage). A total of 31 B-1Bs had received this modification as of July 1988. On the current schedule, all aircraft will be modified by February 1989.

Other Problems

As expected with a complicated weapons system, various problems have emerged with individual parts. For example, one particular electrical generator has repeatedly failed, and some windshields have delaminated. Fixing such problems is part of the ongoing maintenance necessary to keep the B-1B operational.

SUMMARY

The Air Force has made progress in resolving the B-1B's major problems and host of minor problems. The service anticipates that most of the work necessary to solve these problems will be completed within the original $20.5 billion cap (1981 dollars).

Despite progress, however, several of the B-1B's problems may not be solved on the anticipated schedule. It is too soon to predict with confidence that the Stability Enhancement Function for the flight control system will perform as predicted and will be completed in accordance with the planned schedule and budget. Also, following the recent revelation that the architecture of the defensive avionics system has a major deficiency, the Air Force's plan for modifying the system to meet the baseline specifications and installing it by 1992 is in disarray. A new schedule and budget for the defensive avionics system must await completion of the Air Force's study of alternatives. Until these programs are completed, the B-1B's payload, range, and defensive capability will fall short of planned levels.

Even so, there is little controversy over whether work on the baseline B-1B should proceed: the Air Force has carefully prepared the plans for resolving the B-1B's problems, and--with the possible exception of the defensive avionics system--relatively small amounts of funds are at stake. Instead, the significant issue is the appropriate funding level for and direction of enhancements that might eventually provide the B-1B with capability beyond that in the original plans.

CHAPTER III

THE CAPABILITY OF SOVIET AIR DEFENSES AND THE COMPARATIVE MERITS OF PENETRATING AND STANDOFF BOMBERS

Over the next few years, the Congress will have to decide whether to invest substantial additional monies in the B-1B bomber program to enhance the aircraft's ability to penetrate Soviet air defenses and to make it useful in a wider range of combat missions. The value of those enhancements depends on how the United States plans to use the B-1B bomber. Will the bomber be maintained as a penetrator, shifted to a "shoot-and-penetrate" role in which it launches externally carried cruise missiles before penetrating Soviet defenses, or employed as a standoff bomber carrying only cruise missiles?

The choice of how to use the B-1B depends in turn on answers to two basic questions:

- How effective are Soviet air defenses, and how much might they improve in the future?

- What are the advantages of employing the B-1B as a penetrating bomber as opposed to a standoff bomber?

This chapter discusses these two issues as background for considering enhancements to the B-1B that may be proposed in future years.

SOVIET AIR DEFENSES

The Soviet Union's air defenses include surface-to-air missiles (SAMs), fighters carrying air-to-air missiles, and anti-aircraft guns. These assets are supported by a ground-based radar network and airborne radars.

The current Soviet air defense system has had three significant shortcomings. Most important, many portions of the Soviet air defense network, including airfields and ground-based radars, are vulnerable to destruction by U.S. ballistic missiles, which would arrive long before U.S. bombers. Also, the effectiveness of Soviet air defenses is limited by the short range of ground-based radars and the limited ability of fighter aircraft to find low-flying penetrators. These shortcomings have enabled the United States to maintain confidence that a significant percentage of its bombers can penetrate Soviet air defenses and accomplish their missions.

Two factors, however, have refocused attention on the effectiveness of Soviet air defenses. First, the B-1B was deployed with defensive avionics that fall far short of planned capabilities. Second, the Soviet Union is striving to remedy the shortcomings in its air defenses by decreasing its dependence on land-based facilities, deploying longer-range tracking radars on aircraft, deploying "look-down/shoot-down" fighters, and improving its surface-to-air and air-to-air missiles.

How effective are current and planned Soviet air defenses? Evaluations vary widely, depending on the scenario. Two scenarios--one in which the B-1B penetrates easily and the other in which it does not--are presented below. These scenarios reflect differences in circumstances (for example, whether the United States is attacked with or without warning) and in emphasis (for example, using the best-case rather than worst-case assumptions regarding such factors as weapon performance or the impact of a precursor attack on the Soviet command system). They also reflect differences in tactics (such as whether cruise missiles would be used to help destroy Soviet defenses and whether the chosen targets are defended). Depending on the circumstances, emphasis, and tactics considered, the B-1B can appear to be either an effective or ineffective penetrator.

After evaluating these factors in the light of the best available information--including the tactics used in the Strategic Integrated Operational Plan (SIOP, the U.S. blueprint for conducting strategic warfare), and assumptions based on U.S. intelligence data--the Air Force concluded that an acceptable percentage of B-1Bs would succeed in penetrating heavily defended areas well into the 1990s.[1] Because of

1. See testimony by General B. L. Davis, Commander in Chief of the Strategic Air Command, in *Strategic Force Modernization Programs*, Hearings before the Subcommittee on Strategic and Theater Nuclear Forces of the Senate Committee on Armed Services, 97:1 (1981), p. 264.

the problems encountered in fielding the defensive avionics for the baseline B-1B, the percentage of B-1Bs that would penetrate Soviet defenses under almost any given set of assumptions would be lower now than when the Air Force made that evaluation. The Air Force might be able to raise the probability of penetrating Soviet defenses, however, by changing the tactics or the difficulty of the mission, as discussed below.[2]

One Scenario: B-1B Bombers Penetrate Easily. In this scenario, it is assumed that the United States would have time to enhance the survivability of its strategic forces before a Soviet nuclear attack on the United States.[3] Measures to increase survivability might include deploying bombers to a larger number of airfields or placing them on airborne alert and sending all available submarines carrying ballistic missiles to sea. The United States might also prepare to launch its silo-based intercontinental ballistic missiles on warning of a Soviet attack so that they would not be destroyed on the ground.[4]

Thus, a large number of U.S. strategic nuclear weapons would survive a nuclear attack. Some of the warheads on surviving ballistic missiles probably would be dedicated to suppressing Soviet air defenses--attacking such targets as major military airfields, with the intention of destroying Soviet interceptors and their support facilities. As a collateral product of attacks planned and conducted for other rea-

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2. The Institute for Defense Analyses is currently estimating the percentage of B-1Bs that would penetrate Soviet air defenses under specific sets of assumptions. A classified report to the Congress is expected in October 1988.

3. This assumption is based on the argument that a political confrontation would precede a Soviet nuclear attack since, given the risks inherent in nuclear war, the Soviet Union would not consider using nuclear weapons unless major national interests were at stake and other potential solutions had been explored. During an escalating political confrontation, the United States would have time to place its forces on alert. Also, even if a political confrontation did not precede the Soviet attack, U.S. intelligence data might reveal preparations for such an attack, giving the United States time to place its forces on alert.

4. Many analysts doubt the wisdom of attempting to launch ICBMs on warning of a Soviet attack since, if the United States erred in identifying a perceived Soviet attack, it could start a major nuclear war. Such an error is not inconceivable; several incidents have triggered a false indication of a nuclear attack. In one case, the false indication was caused by a malfunctioning computer chip and, in another, by a technician who loaded a test tape with a simulated attack into a computer without making the appropriate notifications. See *Recent False Alerts from the Nation's Missile Attack Warning System*, Hearings before the Senate Committee on Armed Services, 96:2 (1980); and *Failures of the North American Aerospace Defense Command's (NORAD) Attack Warning System*, Hearings before the Subcommittee on Legislation and National Security of the House Committee on Government Operations, 97:1 (1981).

sons, many other airstrips, radars, and surface-to-air missile sites in the Soviet Union probably would be destroyed.

In this scenario, therefore, many Soviet interceptors would be destroyed on the ground, and others might survive but--because the support facilities had been destroyed--would run out of fuel before U.S. bombers arrived. In addition, U.S. bombers would fly routes designed to take maximum advantage of the direct and indirect damage to Soviet air defenses, facilitating their penetration of those defenses. Also, since most Soviet strategic SAMs are not mobile, the B-1Bs' routes would be planned to avoid them.

In this scenario, the challenge posed to penetration by the B-1B would be small. Moreover, the effectiveness of Soviet air defenses could be diminished further by the potential effects of high-altitude electromagnetic pulse and failures in the Soviet command system.

High-altitude electromagnetic pulse (HEMP) is a burst of radio energy generated when gamma rays from an exoatmospheric nuclear explosion collide with the upper atmosphere. This pulse can cause a high-voltage surge of electricity in conductive materials, which can burn out electrical components. Although the B-1B has been designed to resist HEMP, HEMP might damage Soviet radars and missile guidance systems if they have not been similarly protected.

Failures in the Soviet command system could also degrade the performance of the Soviet air defenses. Such failures might include communication equipment damaged by HEMP; satellite and high-frequency radio communications disrupted by blackouts (the absorption of radio signals) and scintillation (the rapid fluctuation in the strength of radio signals) caused by nuclear detonations; and command centers destroyed by nuclear blasts. Damage to the command system would complicate the coordination of Soviet defenses, making it easier for bombers to penetrate them.

One could also argue that Soviet air defense technology will probably not present major challenges to the B-1B's ability to serve as a penetrating bomber through the 1990s. Consider, for example, airborne radars on Soviet AWACS (Airborne Warning and Control System) aircraft, improved missiles, and the potential to intercept bombers farther from Soviet borders. Soviet AWACS have many advantages over ground-based radars but could be highly vulnerable to attacks by fighter aircraft. Nor does deployment of any other effective wide-area tracking system appear imminent (see Appendix B). Although the Soviet Union is deploying more fighter aircraft with the ability to track and attack low-flying bombers, the missiles that the fighters would fire do not appear to be gaining a significant advantage over countermeasures designed to defeat the missiles. Finally, in regard to intercepting bombers farther from its borders, which could give the Soviet Union more time to down bombers before they reach the Soviet borders, no leap in capability appears imminent.

A Second Scenario: The B-1B is Highly Vulnerable. A more pessimistic scenario starts with a different assumption--that the Soviet Union might catch the United States off-guard with a surprise attack, destroying ICBMs in their silos, submarine-launched ballistic missiles on submarines that are in port, and many bombers before they can take off. Thus, the United States would have fewer surviving strategic warheads and might not have enough to allocate some to the task of suppressing Soviet air defenses. Even if some warheads were allocated to that task, the effects might be minimal: the effects of HEMP are uncertain; the Soviet Union might succeed in launching its fighters before U.S. missiles arrived and in refueling them with tanker aircraft or at remote airfields; and the destruction of a few ground-based radars, out of about 10,000 the Soviet Union has deployed, would make no practical difference in Soviet radar coverage. Therefore, in comparison to the previous scenario, fewer U.S. bombers would face a more robust Soviet air defense system.

The predicted success rate of B-1B bombers in penetrating Soviet defenses would decrease further if one used the highest estimates of the effectiveness of Soviet radars and missiles and the lowest estimates of the reliability and accuracy of U.S. weapons and of the effectiveness of U.S. countermeasures (chaff, flares, and electronic countermeasures).

Moreover, the effectiveness of the B-1B bombers depends on the choice of specific missions and tactics. For example, the B-1B's probability of successful penetration would be lower if the selected targets were heavily defended or if the mission was planned such that the B-1B used bombs to attack targets rather than SRAMs, necessitating that it fly over its target. Cruise missiles and short-range attack missiles could be used to suppress defenses as well as to attack targets directly; less than optimal allocation to either task would also lower the B-1B's effectiveness.

Finally, the Soviet Union is continuing to invest heavily in its air defenses. Those defenses could improve substantially as the Soviet Union deploys more interceptors with the ability to detect and attack low-flying bombers and more AWACS for coordinating air defenses over a wide area. These Soviet AWACS might prove to be more effective and difficult to destroy than assumed in the previous scenario.

ADVANTAGES OF PENETRATING AND STANDOFF BOMBERS

The ability of the B-1B to penetrate Soviet defenses is one factor in determining whether to maintain it as a penetrating bomber or to employ it as a standoff bomber that carries cruise missiles. Another factor, of equal importance, is the relative advantage of penetrating and standoff missions. The Air Force argues that penetrating Soviet air defenses with manned bombers provides capabilities that cannot be realized by launching cruise missiles from a bomber flying outside Soviet territory. On the other hand, proponents of standoff bombers contend that many of the Air Force's arguments do not stand up and that cruise missiles are both less expensive and more effective in most missions. This section reviews these opposing views in greater detail after briefly noting some advantages offered by bombers regardless of their mission.

Advantages of Bombers

Penetrating and standoff bombers share some very important advantages that are worth noting to ensure they do not become part of the debate regarding the desirability of the two types of bombers.

- Bombers are considered to contribute more to stability during a crisis than ICBMs or SLBMs. Because bombers are slow, taking many hours to reach the Soviet Union (compared with 15 to 30 minutes for ballistic missiles), they are ineffective tools for conducting a first-strike nuclear attack that would destroy many Soviet weapons, command centers, and communication systems, diminishing Soviet capability to retaliate. For this reason, bombers do not create an incentive for the Soviet Union to prepare to launch its ICBMs on warning of an attack, or to attack in the belief that the United States is preparing such a first strike.

- For several hours after bombers take off en route to the Soviet Union, the Air Force can contact the bombers and cancel a mission. In contrast, ICBMs and SLBMs cannot be recalled once they are launched.

- Bombers are vulnerable if a nuclear warhead detonates at an airfield when they are on the ground, but this vulnerability can be greatly reduced by placing a high percentage of the bombers on strip alert (parked near the runway ready to take off), dispersing them from main operating bases to secondary bases, or placing some on airborne alert.

- The U.S. Administration could send a visible message to the Soviet Union regarding the seriousness of a situation, while stopping well short of war, by changing the alert level of bombers.

- There is a potential synergistic relationship between the survivability of bombers and ICBMs in that, if the Soviet Union configures an attack to maximize the probability of destroying U.S. bombers, the probability of destroying U.S. ICBMs would be diminished, and vice versa. This relationship is explained in more detail in Box 4.

- In an extended nuclear war, bombers could deliver one load of nuclear munitions and then return to pick up a second load, assuming the necessary facilities have survived.

- Bombers can be employed in conventional as well as nuclear conflicts by loading them with different munitions.

BOX 4
Synergistic Relationship Between ICBMs and Bombers

Analysts have long pointed to a potential synergistic relationship between intercontinental ballistic missiles (ICBMs) and bombers. The argument is that, if the Soviet Union configures an attack to maximize the probability of destroying U.S. bombers, the probability of destroying U.S. ICBMs would be diminished, and vice versa.

The first contention--that a Soviet attack configured to maximize the destruction of U.S. bombers would increase the percentage of U.S. ICBMs that would survive--assumes that the Soviet Union would decrease the bombers' warning time by launching its submarine-launched ballistic missiles (SLBMs) and ICBMs simultaneously, with the inaccurate Soviet SLBMs attacking U.S. bomber bases and the accurate Soviet ICBMs attacking U.S. ICBMs. Thus, U.S. bombers would only have about 15 minutes--the flight time of the SLBMs--of warning time to escape their bases. Under this strategy, however, the United States might have time to confirm the detonation of Soviet SLBM warheads on U.S. territory and to launch U.S. ICBMs in retaliation before Soviet ICBMs arrive to attack them.

The second contention--that a Soviet attack configured to maximize the destruction of U.S. ICBMs would increase the percentage of U.S. bombers that would survive--assumes that the Soviet Union would time the launch of its ICBMs and SLBMs so that they would arrive on their respective targets simultaneously. With this strategy, U.S. bombers would have more warning time, and more bombers would escape their bases before the attacking missiles arrived. Because no Soviet SLBM warheads would detonate on U.S. territory before the Soviet ICBMs arrived to attack U.S. ICBMs, however, there is a lower probability that the United States would launch its ICBMs in time to save them. This argument assumes that the United States would hesitate to launch its ICBMs since the evidence of the Soviet attack would be weaker; if the United States launched its ICBMs and its perception of the Soviet attack was incorrect, the United States would have needlessly started a major nuclear war.

Some of the conditions assumed in these scenarios are changing. The scenarios assume, for example, that Soviet SLBMs are too inaccurate to attack U.S. silo-based ICBMs. The accuracy of Soviet SLBMs is improving, however, and they might eventually have a high probability of destroying U.S. silo-based ICBMs. The scenarios also assume that the Soviet Union would launch its SLBMs from close to the United States. As the range of Soviet SLBMs has increased, however, the Soviet Union has tended to keep its SLBM-carrying submarines farther from U.S. shores, increasing their survivability and flight time and thus reducing the distinction between the flight time of SLBMs and ICBMs.

The Case for the Penetrating Bomber

While both penetrating and standoff bombers possess the advantages noted above, advocates of penetrating bombers contend that such bombers have additional advantages that cannot be duplicated by standoff bombers equipped with cruise missiles. These advantages include a superior ability to:

- Attack hardened targets;
- Conduct damage assessment/strike missions;
- Attack mobile or relocatable targets;
- Defeat terminal Soviet air defenses; and
- Deliver conventional munitions.

The penetrating bomber also offers advantages under counting rules being proposed during the Strategic Arms Reduction Talks (START).

The Hard-Target Mission. The penetrating bomber can effectively attack targets hardened against nuclear blasts because it can carry large bombs and deliver them accurately. Cruise missiles cannot currently match this capability. Although they are accurate, they cannot carry bombs with the large yields that bombers can carry. The currently deployed ALCM-B carries one W80-1 warhead with a reported yield of about 200 kilotons (kt). The B-1B can carry a variety of bombs including the B61 (reported yield of 100 to 500 kt) and the B83 (reported yield in excess of 1,000 kt).[5]

The Damage Assessment/Strike Mission. It is conceivable that in a U.S. nuclear attack on the Soviet Union, some targets would be targeted with a ballistic missile warhead and then, hours later, U.S. bombers could fly over the targets to determine (using high-resolution radar) whether the targets were destroyed. If they were not destroyed,

5. For the yield of warheads, see Thomas B. Cochran, William M. Arkin, and Milton M. Hoenig, *Nuclear Weapons Databook, Volume 1: U.S. Nuclear Forces and Capabilities* (Cambridge, Mass.: Ballinger, for the Natural Resources Defense Council, Inc., 1984), pp. 65, 175, and 199.

the bombers would be authorized to attack them again using either a bomb or a SRAM.

Strategic Relocatable Targets. The Air Force argues that penetrating bombers are well-suited for attacking a growing category of mobile targets collectively called strategic relocatable targets (SRTs). This category includes diverse assets such as trains, ships, planes, mobile ICBMs, and armies maneuvering out of garrison.

This group of targets has attracted interest because, as the accuracy of U.S. ballistic missiles has improved, the Soviet Union has put greater reliance on mobility to maintain the survivability of important sensors, command centers, and weapons. For example, the Soviet Union is deploying the rail-mobile SS-24 ICBM and the road-mobile SS-25 ICBM, possibly in response to the pending deployment by the United States of the highly accurate MX ICBM and Trident II SLBM.

The Air Force contends that the United States should be able to target such SRTs to deter a Soviet decision to employ nuclear weapons. The argument that this capability will increase deterrence has two components. The first component is that this capability would prevent the Soviet leaders from initiating a war against the United States with the expectation that the Soviet Union would have a survivable reserve of strategic nuclear weapons with which it would be able to pressure the United States for concessions. The second component is based both on current U.S. strategic policy, which contends that deterrence is strengthened by the ability to threaten the facilities that the Soviet leaders value highly, and on the assumption that Soviet leaders clearly value those assets, such as mobile ICBMs, that they have taken great efforts to protect.

The Air Force argues that the penetrating bomber is well suited for attacking such mobile targets for two reasons: the bomber carries both sensors and weapons, eliminating the problem of communicating between a sensor platform and a weapon platform; and the bomber crew can make the final identification of a mobile target before attacking it.

Terminal Defenses. A cruise missile approaches a target at a low altitude and slow speed. A penetrating bomber, on the other hand, can either approach the target at a low altitude and drop bombs or by-pass the target and fire short-range attack missiles, which are difficult to intercept because they approach the target at a high speed and a high angle. Thus, the penetrating bomber, compared with cruise missiles, has a better chance of overcoming terminal defenses.

Furthermore, the Air Force argues that cruise missiles and penetrating bombers, in combination, present the Soviet Union with a diverse threat that forces the Soviet Union to expend greater resources on air defense, reducing the resources available to meet other military requirements.

Conventional Missions. A penetrating bomber designed to carry nuclear munitions through Soviet air defenses can also be well qualified to carry conventional munitions on a penetrating mission. Thus, the B-1B, if maintained as a penetrating strategic bomber, could be available for use as a conventional bomber in other parts of the world.

Arms Control. In the START negotiations, the United States and the Soviet Union have tentatively agreed to a ceiling on strategic warheads under which bombs and SRAMs would be discounted. Specifically, rather than each bomb or SRAM counting as one warhead, all of the bombs and SRAMs on a penetrating bomber would count as a single warhead.

The general rationale for discounting the bombs and SRAMs carried on penetrating bombers is that penetrating bombers must traverse Soviet air defenses, creating the possibility that a significant percentage will not reach their destination. Also, a bomber on a mission might only carry one-third to two-thirds of the bombs and SRAMs it is theoretically capable of carrying. For both reasons, if the counting rules credited a bomber with carrying as many warheads as it can carry, the counting rules would overcount the relative strength of the bomber force. Finally, it might make sense to discount bombs and SRAMs to encourage their deployment, since weapons on a bomber do not pose the same first-strike threat as the warheads on a ballistic missile, which can reach a target in the Soviet Union in 15 to 30 minutes rather than 8 to 14 hours.

Since this discount would not apply to air-launched cruise missiles (a bomber equipped to carry cruise missiles would be counted as carrying some larger number of warheads yet to be negotiated), the United

States could retain more warheads by deploying penetrating bombers armed with bombs and short-range missiles than it could by deploying standoff bombers armed with cruise missiles. According to press reports, the United States' negotiating team is seeking to have each bomber equipped to carry cruise missiles count as about 10 warheads under the warhead ceiling.

The Case for the Standoff Bomber

The proponents of standoff bombers present three basic points. First, standoff bombers with cruise missiles are more effective than penetrating bombers and are also less expensive. Second, it would not serve U.S. interests to favor penetrating bombers over standoff bombers in future arms control agreements. Third, there are no special missions--hard-target missions, damage assessment/strike missions, SRT missions, and conventional missions--for which penetrating bombers are better suited than cruise missiles.

Greater Effectiveness. Proponents of standoff bombers contend that cruise missiles launched from standoff bombers can do a better job of penetrating current and future Soviet air defenses than penetrating bombers.

Cruise missiles exploit three weaknesses in Soviet defenses. They fly low to the ground beneath the coverage of ground-based radars; with stealth technology, they will be difficult for future Soviet AWACS and fighters with look-down radars to detect; and, perhaps most important, they inundate defenses. A single Soviet fighter, for example, could destroy perhaps 16 warheads by intercepting a penetrating B-1B bomber, but the fighter has little hope of intercepting more than one or two of the up to 20 cruise missiles that can be launched by the B-1B operating as a standoff bomber.

In addition, if the Soviet Union attempts to intercept standoff bombers before they release their cruise missiles, the United States could employ many simple countermeasures. It could delay the attack (which might leave Soviet interceptors running out of fuel while flying over the ocean), increase the range of the cruise missiles (which might force the Soviet interceptors to fly out so far they have little time to intercept the bombers before running out of fuel), or alter the bombers' routes so that they approach the Soviet Union from directions that are more poorly defended.

Moreover, there is a great deal of future flexibility inherent in cruise missile technology. For example, the United States is working on an earth-penetrating warhead for a cruise missile that would make it a more effective weapon against underground facilities and ICBM silos. Cruise missiles can also be used in tandem, with one detonating to destroy concentrated air defenses while the second follows to attack the primary target. In addition, the guidance and flight control system of cruise missiles can be improved so that, instead of following fairly direct paths to their targets, they take more deceptive routes. The payload aboard cruise missiles could also be altered so that several missiles within a larger group would serve as decoys to draw Soviet interceptors away from the rest.

Cost Effectiveness. If the United States were only to pursue a standoff capability in the future, relying on the ability of its B-52 and B-1B bombers to carry cruise missiles, it would be able to save money by canceling both the SRAM II program, which is developing an improved short-range attack missile, and the B-2 stealth bomber. The B-52 is aging, however, and if the United States needed more than 100 standoff bombers, it might eventually have to build a new bomber to carry cruise missiles. But a new bomber designed to stand off and launch cruise missiles would be cheaper than building the B-2, since it would not have to be designed for the demanding task of penetrating Soviet defenses. Also, the new bomber could be configured to eliminate the need for refueling by tanker aircraft, which are an expensive component of the current system of penetrating bombers. Finally, stealth technology might be more easily and cheaply incorporated in cruise missiles than in penetrating bombers, because cruise missiles are small and do not need cockpits, bomb bays, and landing gear (cavities and discontinuities in the skin are a major challenge in reducing an aircraft's radar cross section).

Arms Control. As noted earlier, the proposed strategic agreement under discussion in Geneva counts a penetrating bomber as only one warhead under the warhead ceiling but counts a bomber equipped to carry cruise missiles as carrying some higher, yet to be negotiated, number. This formulation could be considered advantageous to the United States, since the United States has more penetrating bombers.

Supporters of cruise missiles could argue, however, that the proposed agreement actually favors the Soviet Union by forcing the United States to pursue the more expensive, less effective strategy of deploying penetrating bombers instead of the cheaper, more effective strategy of deploying standoff bombers. (Indeed, this interpretation would fit with the long-standing Soviet aversion to permitting the deployment of long-range cruise missiles in a strategic arms agreement.) If so, perhaps the United States should change course and pursue an agreement that treats penetrating and standoff bombers equally so as not to preclude a future decision to opt for standoff over penetrating bombers.

The Hard-Target Mission. Attacking hardened targets is one of several missions for which the advocates of penetrating bombers claim the penetrating bomber is better suited than cruise missiles launched by standoff bombers. Proponents of standoff bombers, however, contend that the claims in support of penetrating bombers on these special missions are overstated and the claims for cruise missiles understated.

Although a penetrating bomber can carry a bomb with a more powerful warhead than that carried on a cruise missile, this capability does not demonstrate that the penetrating bomber is a better weapon for attacking hardened targets. First, despite its smaller warhead, a cruise missile is about as effective as a bomb against many hardened targets because of its high accuracy. Based on public reports of its accuracy and yield, the ALCM-B would have about a 99 percent probability of destroying a target hardened to withstand a pressure of 500 pounds per square inch (psi), which is representative of medium-hard facilities such as munitions bunkers, leadership bunkers, and older Soviet ICBM silos. It would have about an 87 percent probability of destroying a target hardened to withstand a pressure of 5,000 psi, which is representative of very hard facilities such as newer Soviet ICBM silos and command centers buried deep underground.

Second, many hardened targets would be defended, making it likely that bombers would attack them with SRAMs rather than bombs, since SRAMs enable the bomber to bypass rather than fly over the target. Cruise missiles are more effective than the currently deployed SRAM-A, which has relatively poor accuracy, and might be as effective as the SRAM II now being developed.

Third, the capability of cruise missiles against hardened targets could theoretically be increased by equipping them with warheads that would penetrate into the earth and then detonate, rather than detonate as the cruise missile flies over a target. Such warheads would increase the amount of energy converted into shock waves traveling through the earth, increasing the warhead's destructive ability against hardened facilities such as underground command centers and ICBM silos. One potential drawback might be that the cruise missile would have to fly at higher altitudes approaching a target, making it easier to track.

Nevertheless, and perhaps most important, neither penetrating bombers nor standoff bombers equipped with cruise missiles may be the best weapons for attacking hardened targets such as silo-based ICBMs and command centers that might be used to coordinate a Soviet attack on the United States. If the goal is to prevent such an attack, accurate ballistic missiles like the MX ICBM and the forthcoming Trident II SLBM, which can reach the target in 15 to 30 minutes rather than in the 8 to 14 hours required by a bomber, may be preferable.

<u>The Damage Assessment/Strike Mission</u>. Advocates of standoff bombers argue that the special capability of penetrating bombers on damage assessment/strike missions is exaggerated. First, it might be difficult for a bomber to determine whether a facility, particularly a hardened underground facility, has been destroyed because much of the damage may be hidden. Second, flying over the target to determine whether it has been destroyed might expose the bomber to Soviet air defenses, decreasing the probability that the bomber would complete other parts of its mission.

Third, if a facility is important enough to justify risking a bomber in this fashion, then it is important enough to justify a simpler measure which is as or more effective: target the facility with a second warhead initially. If the target might contribute to a subsequent Soviet attack on the United States, planners might choose a fast-arriving ballistic missile warhead as the second warhead. If it is not important that the target be destroyed quickly, then it makes sense to use a cruise missile rather than a penetrating bomber to deliver the second warhead. This approach leaves the penetrating bomber free to pursue other tasks and spares it from the high-risk task of flying over potentially defended targets at low altitudes.

Finally, if there is a pressing need for damage assessment, high-altitude intelligence planes might be better suited to the task than low-altitude bombers.

Strategic Relocatable Targets. It is also unclear that the penetrating bomber serves a vital function in relation to attacking mobile and relocatable Soviet facilities.

First, although the number of mobile and relocatable Soviet facilities is growing, developing the capability to target them may not be in the best interest of the United States. Mobile Soviet ICBMs capable of surviving a U.S. attack, for example, potentially have the same stabilizing function during a crisis as the highly survivable U.S. SLBMs. If a portion of the Soviet strategic forces is highly survivable, the Soviet leadership would have less concern during a crisis that the United States might attack the Soviet Union, decreasing the pressure either for preparing to launch ICBMs on warning of a U.S. attack or for considering the use of a preemptive strike. By alleviating this pressure, survivable Soviet mobile missiles decrease the probability that a crisis would escalate into nuclear war.

Moreover, even if the United States wants to target mobile missiles and other SRTs, the technology for doing so with a bomber is immature. Basic requirements that a bomber must meet to be effective against SRTs include:

- **Search Capability.** A bomber must have enough range, in combination with the swath of ground the sensors can see at any one point, to search a large amount of territory.

- **Sensor Capability.** The resolution (size of object a sensor can detect) and sensitivity of the sensors in their proposed operating modes must be high enough to distinguish between similar objects such as a truck carrying freight and a truck carrying a missile.

- **Cueing.** To search for a mobile target, a bomber needs an estimate of its location. Because a mobile target can move